SUPER
Sustainable fUture steel Production and pEople Recruiting and skilling

K1 MET
metallurgical competence center

BFI
Excellence in Applied Research

Decarbonisation technologies in the iron and steel industry

Monika Häuselmann, Lukas Schmidt, K1-MET
Jonas van Bracht, BFI

19-02-2026 | Online-Webinar

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101216382

AGENDA

10 min | Welcome and introduction to the SUPER project

15 min | Overview of decarbonisation technologies

5 min | Scenario development

25 min | Q&A and discussion

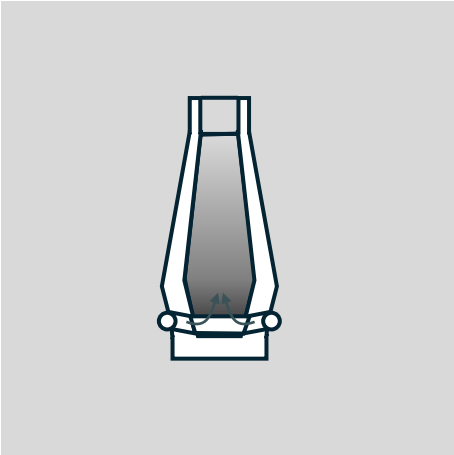
5 min | Conclusion

INTRODUCTION

PROJECT OVERVIEW

SUPER

IRON AND STEEL INDUSTRY - FACING A DUAL CHALLENGE



TECHNOLOGICAL TRANSFORMATION

New processes, energy sources, digital tools and management

SUPER PROJECT

Innovative approach combining both topics and identifying synergies which support the solution to the challenges

WORKFORCE TRANSFORMATION

Loss of experience due to retirements, lack of qualified young talent

PROJECT OVERVIEW

SUPER - SUSTAINABLE FUTURE STEEL PRODUCTION AND PEOPLE RECRUITING AND SKILLING

CONSORTIUM

VDEh-Betriebsforschungsinstitut GmbH (coordinator)
RINA Consulting - Centro Sviluppo Materiali
K1-MET GmbH
Technische Universität Dortmund
EIT Raw Materials GmbH
Scuola Superiore Sant'Anna
Sieć Badawcza Łukasiewicz – Górnośląski Instytut Technologiczny
European Steel Technology Platform

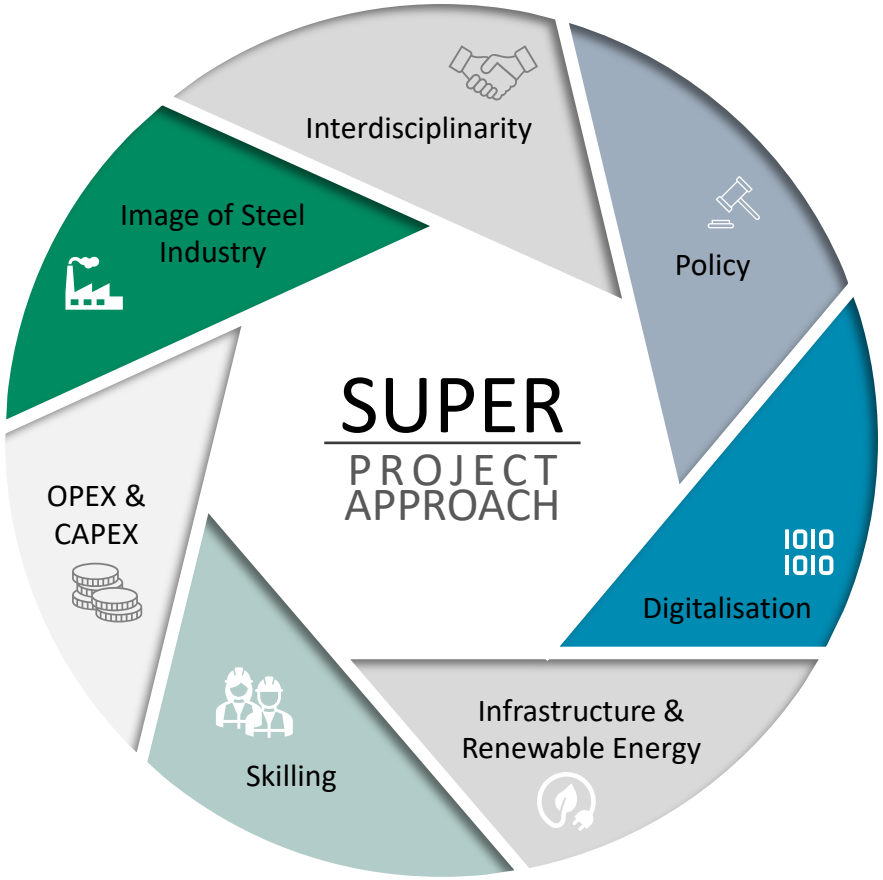
DURATION

01.06.2025 to 30.05.2027

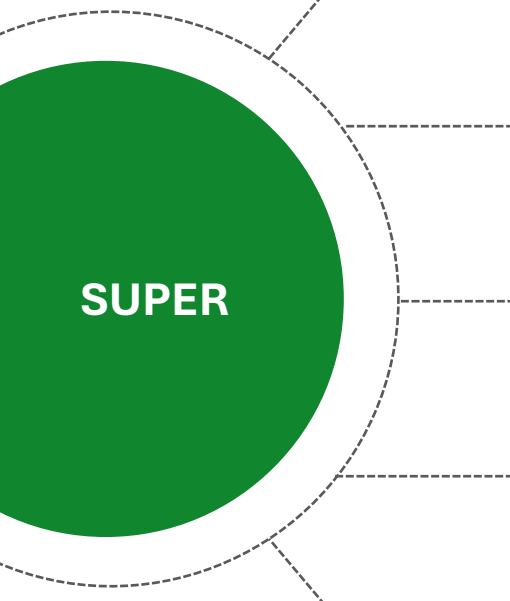
FUNDING

Research Fund for Coal and Steel (RFCS)

https://www.project-super.eu/



ACTIVITIES & ACTIONS



TECHNOLOGY REVIEW | Literature review, fact sheets, decarbonisation scenarios

STAKEHOLDER CONSULTATION | In-depth interviews

RECRUITING & SKILLING | RACE-Events

RECOMMENDATIONS | Recommendations for future activities and policy initiatives

DISSEMINATION & NETWORKING | 4 Workshops, 2 Webinars, LinkedIn, SUPER website

DISCUSSION & FEEDBACK

TECHNOLOGY ROUTES & FEEDBACK

- Does the presented data reflect your understanding?
- Are there additional aspects that should be included to complete the picture?

OUTLOOK & MILESTONES

- How do you see the development of these technologies evolving?
- What milestones must be achieved by 2040 to ensure large-scale deployment by 2050?
- Which innovations or cross-sector synergies could significantly accelerate its development and (cost) competitiveness?

OVERVIEW

DECARBONISATION TECHNOLOGIES

SUPER

APPROACH & DEFINITIONS

Review and analysis

- Technical examination and analysis of CO_2 mitigation technologies in the iron and steel industry
- RFCS LowCarbonFuture, RFCS Green Steel for Europe (GS4E)
- Focus on primary steelmaking

Technology route

- Integration of technologies into a full system (process chain)

CO_2 mitigation potential

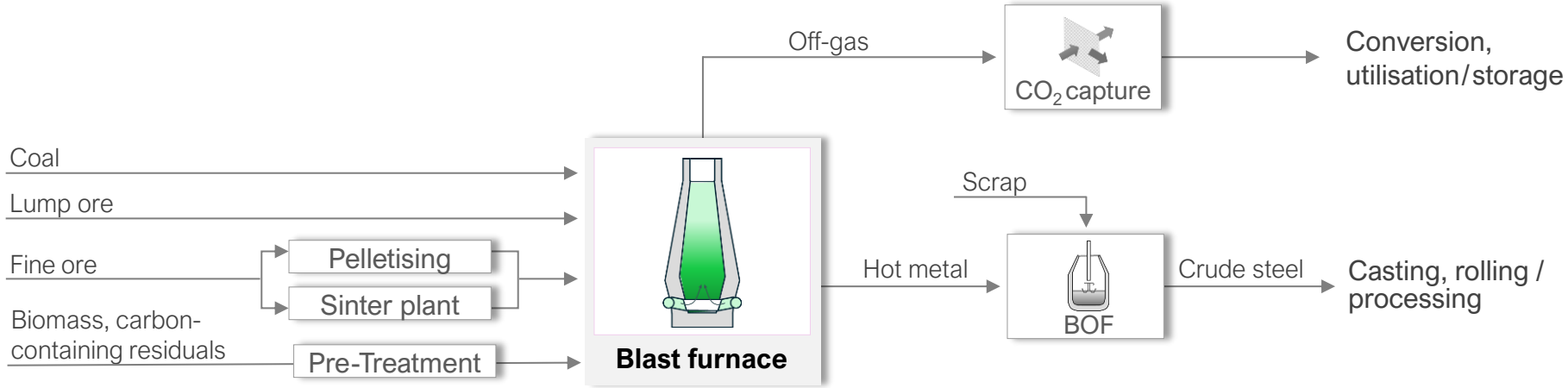
- Direct emissions
- Compared to conventional blast furnace – basic oxygen furnace (BF-BOF) route

TECHNOLOGIES & TECHNOLOGY ROUTES

LOW-CARBON BLAST FURNACE - BASIC OXYGEN FURNACE

Multiple technologies and technology combinations are possible

- Gas injection into the BF
- Alternative carbon sources
- Partial replacement of carbon with hydrogen and electricity
- Top gas processing and recycling
- Integration of carbon, capture and utilisation and/or storage (CCU/S)



TYPICAL APPLICATION
Retrofitting of existing integrated steel plants

RAW MATERIAL
Iron ore, coke, coal, scrap, optional: hydrogen, biomass, DRI, renewable power

CO_2 MITIGATION POTENTIAL
Depending on specific combinations

TRL
Decarbonisation add-ons: TRL 6-8

INITIATIVES (EXAMPLES)
3D/DMX, EASyMelt, Carbon2Chem, H2II

SUPER

TECHNOLOGIES & TECHNOLOGY ROUTES

LOW-CARBON BLAST FURNACE - BASIC OXYGEN FURNACE

CHALLENGES & RESEARCH NEEDS

- Public acceptance of coal-based production technologies low
- Hydrogen injection, top-gas recycling, and CCU/S require modifications (e.g. modification of injection systems)
- No commercial-scale CO_2 capture plants for blast furnace-based steelmaking in operation, CO_2 transport/storage networks needed
- Limited availability of sustainable biomass resources, large-scale supply of green hydrogen needed

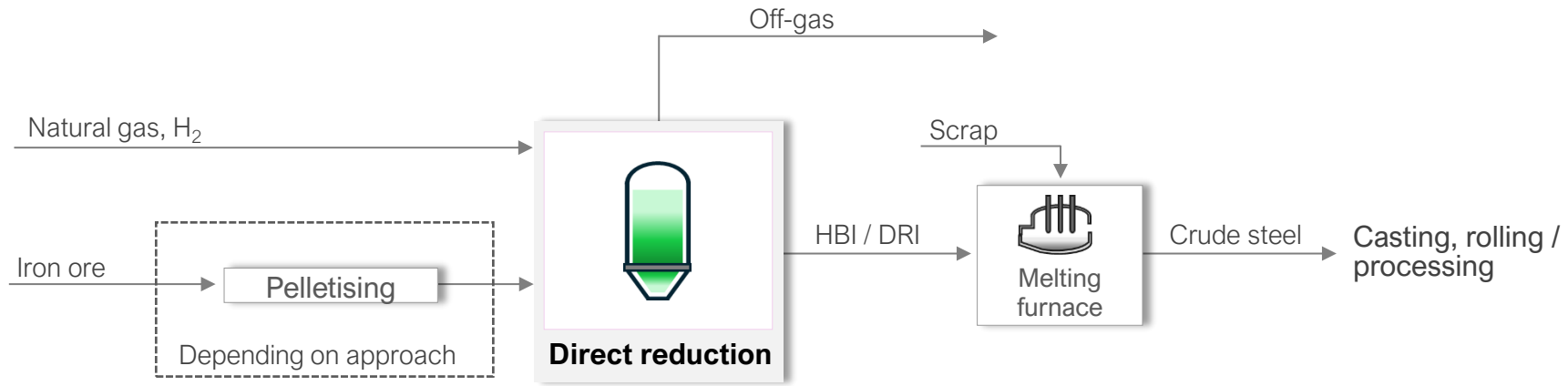
CURRENT PROGRESS

- TRL varies by specific implementation
- Top gas recycling: demonstrated not yet commercial
- Hydrogen injection: TRL 6-8 depending on hydrogen share and site conditions
- CCU/S: Pilot to early commercial capture from blast furnace gas streams

TECHNOLOGIES & TECHNOLOGY ROUTES

DIRECT REDUCTION

In the direct reduction process, iron ore is reduced to DRI by means of reducing gas (e.g. natural gas, hydrogen). Different approaches (e.g. fluidised bed direct reduction, shaft furnace) are currently developed. The process delivers solid material and has to be combined with subsequent smelting.



TYPICAL APPLICATION
Greenfield or as BF replacement; combined with a melting furnace

RAW MATERIAL
Iron ore, hydrogen, natural gas

CO_2 MITIGATION POTENTIAL
Up to -97% with 100% H_2 *

TRL
Fully mature with natural gas; announcements of commercial plants (TRL 8 –9)
2025–2030 for 100% H_2

INITIATIVES (EXAMPLES)
HYBRIT, greentec steel, ArcelorMittal Gijón, Hy4Smelt, SALCOS, HBI C-Flex, MaxHDR

SUPER

TECHNOLOGIES & TECHNOLOGY ROUTES

DIRECT REDUCTION

CHALLENGES & RESEARCH NEEDS

- Insufficient availability of direct reduction (DR)-grade pellets
- Electric arc furnace melting process must be adapted
- Large renewable electricity demand needed, H_2 likely to remain scarce & prohibitively expensive in the coming years
- New infrastructure for hydrogen production, transport and storage

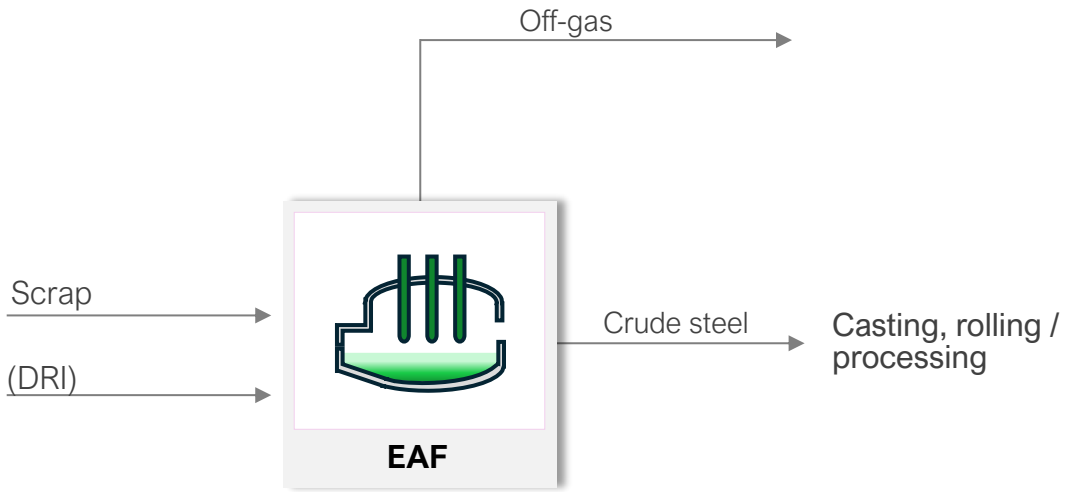
CURRENT PROGRESS

- Commercially available before 2030 (H_2-based)
- Fluidised bed H-DRI technology has been in development for years, with several small industrial-scale demonstration plants operating worldwide
- Multiple projects focusing on hydrogen based direct reduction

TECHNOLOGIES & TECHNOLOGY ROUTES

ELECTRIC ARC FURNACE (EAF)

EAF steelmaking is a process that uses high-power electric arcs from electrodes to melt scrap and other materials, like direct reduced iron (DRI), to produce steel.



TYPICAL APPLICATION
Scrap-based steel production; increasingly combined with DRI for primary steelmaking

RAW MATERIAL
Steel scrap and/or DRI

CO_2 MITIGATION POTENTIAL
-99 % (with renewable electricity and carbon input from sustainable biomass)

TRL
Scrap-based: Fully commercial and globally established

INITIATIVES (EXAMPLES)
CAESAR, DiGreeS, PURESCRAP

SUPER

TECHNOLOGIES & TECHNOLOGY ROUTES

ELECTRIC ARC FURNACE (EAF)

CHALLENGES & RESEARCH NEEDS

- Scrap quality and availability; integration of DRI/HBI in particular with no/low carbon content
- Requires renewable energy (decarbonisation of electricity system)
- Measures that support the recycling and reuse of steel must be enhanced, from the design of products to the end-of-life treatment of scrap
- Innovations in sorting, and contaminant removal to improve scrap feedstock value and expand usable scrap pools needed

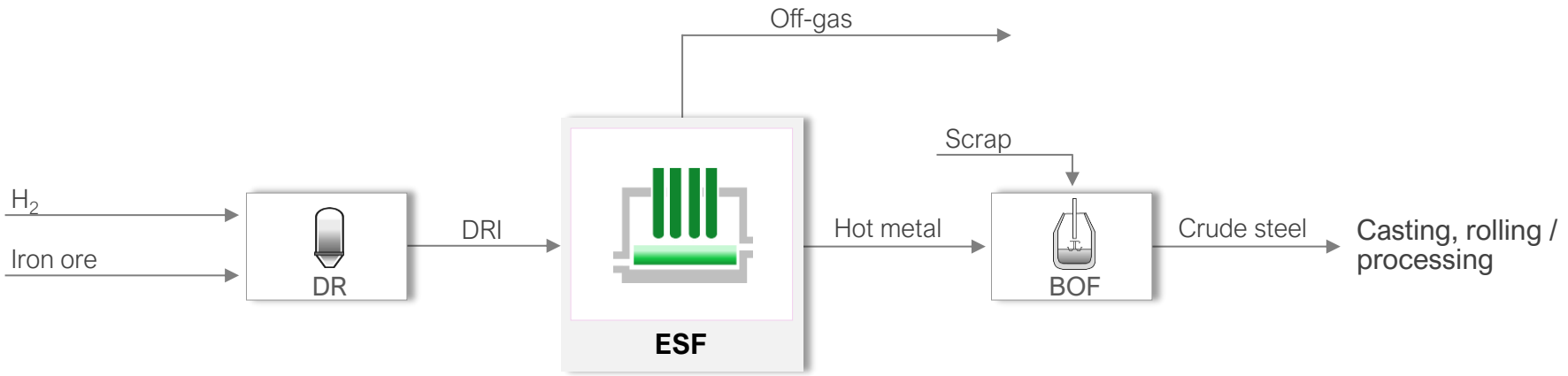
CURRENT PROGRESS

- TRL varies by specific implementation
- Projects focusing on advanced sorting, contaminant removal systems digitalization and advanced process control

TECHNOLOGIES & TECHNOLOGY ROUTES

ELECTRIC SMELTING FURNACE (ESM)

Electric smelting furnace (submerged arc furnace, open slag bath furnace) for ironmaking used for melting and final reduction of DRI based on low and medium grade iron ores.



TYPICAL APPLICATION
Typically combined with direct reduction and BOF steelmaking

RAW MATERIAL
DRI/HBI/PRI, iron containing by-products, carbon containing materials

CO_2 MITIGATION POTENTIAL
-98%

TRL
Not yet been demonstrated on a commercial scale; current stage (2024) of development: system testing (TRL8-9)

INITIATIVES (EXAMPLES)
tkH_2Steel, Hy4Smelt

SUPER

TECHNOLOGIES & TECHNOLOGY ROUTES

ELECTRIC SMELTING FURNACE (ESM)

CHALLENGES & RESEARCH NEEDS

- Large-scale green hydrogen production, transport and storage infrastructure needed
- Availability of renewable carbon input and renewable electricity needed
- Furnace design of a smelter, detailed design of the process route (beneficiation of the ore to higher qualities, carbon content, and metallisation of DRI, carbon in smelter hot metal, optimized scrap rates, etc.).

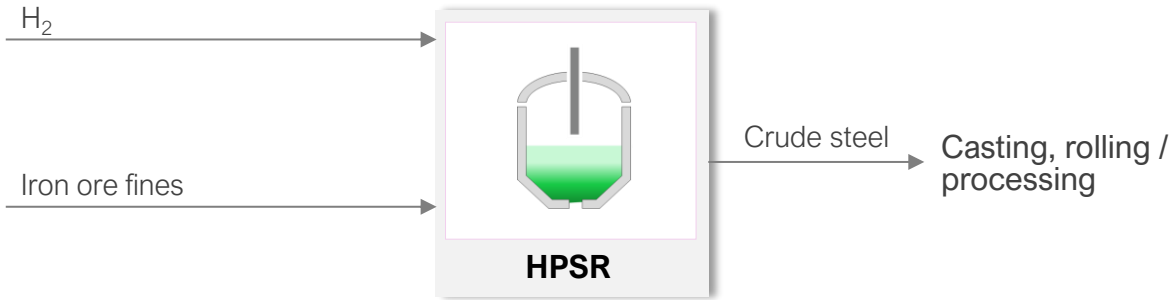
CURRENT PROGRESS

- Not yet been demonstrated on a commercial scale
  Current stage (2024) of development: System testing (TRL8-9)
- Expected readiness for use: 2027-2030

TECHNOLOGIES & TECHNOLOGY ROUTES

HYDROGEN PLASMA SMELTING REDUCTION (HPSR)

HPSR is a direct transformation from iron oxides into liquid steel by means of ionised H_2 (H^+, hydrogen plasma).



TYPICAL APPLICATION
Greenfield; direct ironmaking

RAW MATERIAL
Iron ore fines, hydrogen

CO_2 MITIGATION POTENTIAL
Up to - 95%

TRL
Existing HPSR demonstration plant

INITIATIVES (EXAMPLES)
ROC, SuS-F

SUPER

TECHNOLOGIES & TECHNOLOGY ROUTES

HYDROGEN PLASMA SMELTING REDUCTION (HPSR)

CHALLENGES & RESEARCH NEEDS

- Large renewable electricity demand needed, H_2 likely to remain scarce & prohibitively expensive in the coming years
- New infrastructure for hydrogen production, transport and storage
- Process optimisation (e.g. incorporation of a pre-reduction and pre-heating stage) and upscaling
- Valorisation industrial side streams to maximise resource efficiency

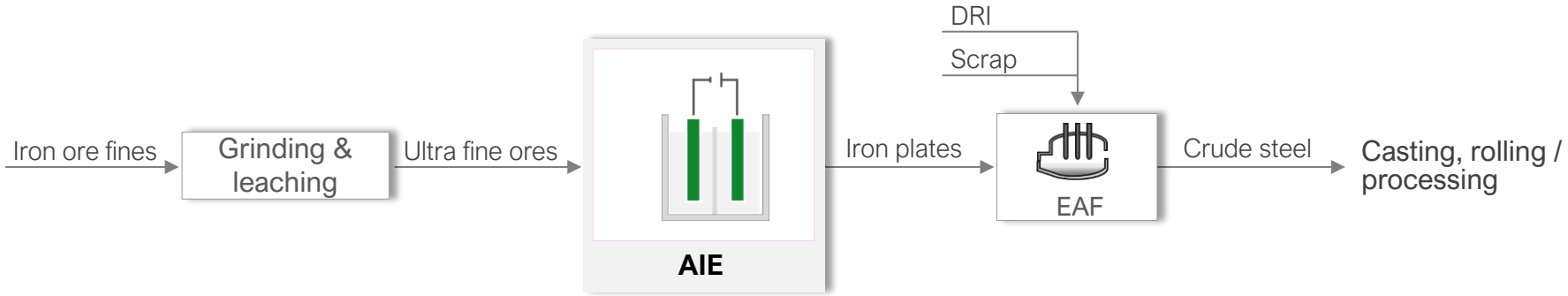
CURRENT PROGRESS

- Existing HPSR demonstration plant (planed upscaling to 200 kg/h)
- TRL (2024): 5
- TRL (2025 - 2030): 7

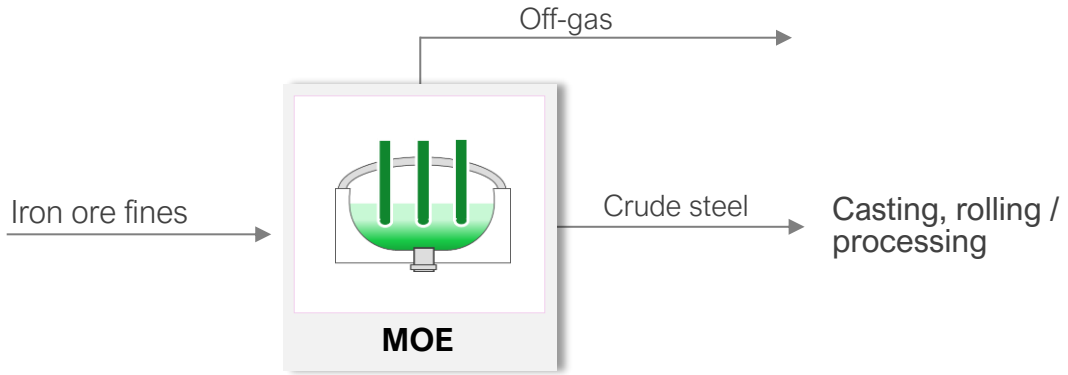
TECHNOLOGIES & TECHNOLOGY ROUTES

IRON ORE ELECTROLYSIS

Low temperature alkaline iron ore electrolysis (AIE), or electrowinning, is the direct deposition of iron from its ores on an electrode.



In the molten oxide electrolysis, iron ore is converted electrochemically to oxygen and iron in an electrolysis cell.



TYPICAL APPLICATION
Greenfield; direct electrochemical iron production

RAW MATERIAL
Iron ore

CO_2 MITIGATION POTENTIAL
Overall footprint depends on renewable electricity supply

TRL
AIE: Pilot plant; expected readiness for use: 2040 – 2045
MOE: Pilot stage; early industrial demonstration (TRL ~5–7)

INITIATIVES (EXAMPLES)
Volteron, Boston Metal

SUPER

TECHNOLOGIES & TECHNOLOGY ROUTES

IRON ORE ELECTROLYSIS

CHALLENGES & RESEARCH NEEDS

- Large renewable electricity demand needed (dedicated electricity infrastructure my be required)
- Further TRL development needed
- Research regarding optimal technology design

CURRENT PROGRESS

- Availability: 2035-2045

TECHNOLOGIES & TECHNOLOGY ROUTES

SUPPORTING TECHNOLOGY: CCU/S

CCU is defined the overall process of capturing carbon oxides from industrial or energy-related sources and converting them into valuable products.

CCUS extends this concept by additionally enabling the permanent storage of captured carbon oxides.

Key R&D needs in steel CCUS are integrating CO_2 capture and utilisation into existing steel plants without disrupting production, enabling sector coupling and industrial clusters to valorise captured CO_2, and developing large-scale industrial demonstration along with transport, storage, and utilisation infrastructure to advance TRLs and de-risk technologies.

Current developments

- Numerous European research, pilot and demonstration projects address CCU and CCUS technologies in the iron and steel industry
- Several projects focus on carbon utilisation routes
- CCU and CCUS technologies for the iron and steel industry span a broad range of TRLs, from laboratory-scale research to advanced industrial pilot and demonstration plants. Several capture technologies have reached high demonstration maturity.

UPDATE Scenario Development

SUPER

METHODOLOGY AND CONTEXTUAL UPDATED

Continuation of the Green Steel for Europe (GS4E) methodology

- Leveraging the proven GS4E approach to ensure maximum validity and comparability of results.

Contextual re-assessment (post-2021)

- Comprehensive update of framework conditions to reflect the shifted geopolitical and economic landscape (e.g. energy crisis, impact of the war in Ukraine, and revised natural gas availability).

Validation of framework conditions

- Using stakeholder surveys and expert consultations to re-validate barriers and drivers (e.g. availability of affordable renewable electricity and green hydrogen).

Technological alignment

- Integrating updated technical trends and recent publications into the existing technology routes, ensuring the scenarios reflect the current state-of-the-art.

SCENARIOS, METRICS AND TARGETS

Update and refinement of three distinct industrial transformation scenarios for 2030, 2040, and 2050

- Reference Scenario: Based on current trends and planned roadmaps
- Mixed Implementation: A plausible mix of various technology pathways
- Impact-based Scenario: Assessing the sensitivity to changed framework conditions

Focus of primary steel production

- Concentration on the most energy-intensive processes while maintaining a basic analysis of secondary processes.

Key quantitative outputs per scenario

- Annual production volumes: Projected output per technology route
- CO_2 emission profiles: Calculation of mitigation milestones
- Resource demand: Specific requirements for renewable energy, H_2, and raw materials

Q&A Discussion & Feedback

SUPER

DISCUSSION & FEEDBACK

TECHNOLOGY ROUTES & FEEDBACK

- Does the presented data reflect your understanding?
- Are there additional aspects that should be included to complete the picture?

OUTLOOK & MILESTONES

- How do you see the development of these technologies evolving?
- What milestones must be achieved by 2040 to ensure large-scale deployment by 2050?
- Which innovations or cross-sector synergies could significantly accelerate its development and (cost) competitiveness?

SUPER
Sustainable fUture steel Production and pEople Recruiting and skilling

K1 MET
metallurgical competence center

BFI
Excellence in Applied Research

Decarbonisation technologies in the iron and steel industry

Monika Häuselmann, Lukas Schmidt, K1-MET
Jonas van Bracht, BFI

19-02-2026 | Online-Webinar

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101216382